Potential Postharvest Use of Radiography to Detect Internal Pests in Deciduous Tree Fruits[1]

James D. Hansen,[2] Donald W. Schlaman,[3] Ron P. Haff[4] and Wee L. Yee

USDA-ARS YARL, 5230 Konnowac Pass Road, Wapato, Washington 98951 USA

J. Entomol. Sci. 40(3): 255-262 (July 2005)

Abstract Radiographic techniques were investigated for their potential to detect internal pests in deciduous tree fruits. Two non-destructive methods, X-ray CT imaging and film X-ray, were used to detect larval feeding damage caused by codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), in apples. In addition, CT imaging was used to detect larvae of the codling moth and western cherry fruit fly, *Rhagoletis indifferens* Curran (Diptera:Tephritidae), in cherries. Both techniques showed evidence of codling moth feeding tunnels in apples, as well as in cherries using CT imaging. CT images of cherries infested with fruit fly larvae showed retraction of the fruit pulp from the seed. This study supports the use of radiography to detect internally damaged fruits for sorting on the commercial packing line.

Key Words *Cydia pomonella*, codling moth, *Rhagoletis indifferens*, western cherry fruit fly, X-ray, non-destructive detection, apple, cherry

International commerce of fresh fruits is restrained by quarantine regulations of the importing country. For example, Japan currently requires apples from the U. S. to be fumigated with methyl bromide to control the codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), an important quarantine pest. Although current legislation still allows the use of methyl bromide fumigation as a postharvest quarantine treatment, future use is uncertain. In addition, health and environmental regulations restricting the use of other fumigants are increasing.

One strategy to eliminate the need for fumigation is the *systems approach,* in which the problem is addressed at a number of points in the commercial operation, with the cumulative effect of eliminating the pest. An automated method to detect and remove infested fruits would increase the productivity of the systems approach, as culling and sorting fruits by hand is labor intensive and time consuming. Currently, production line labor accounts for >20% of the total costs of the final product (Anon. 2002). Automation would reduce these costs and increase efficiency in the packing line.

Radiography is a potential method to automate the culling and sorting operations along the packing line. Whereas linescan X-ray machines have found extensive use

Send correspondence to: James D. Hansen USDA-ARS-YARL 5230 Konnowac Pass Road Wapato, WA 98951 USA Phone: 509-454-6573 Fax: 509-454-5646 E-mail: jimbob@yarl.ars.usda.gov

[1]Received 17 December 2004; accepted for publication 15 January 2005.

[2]Address inquires (email: jimbob@yarl.ars.usda.gov)

[3]Yakima Valley Memorial Hospital, 2811 Tieton Drive, Yakima, WA 98902

[4]USDA-ARS-WRRC, 800 Buchanan St., Albany, CA 94710

in the food industry, they are generally limited to identifying relatively large defects or contaminants such as bone, glass, or metal fragments. Commercial detection of insects using X-ray has been limited to sampling with film, as real-time digital X-ray detectors with sufficient resolution have only recently become available. Real-time detection of insects using X-ray, although not commercialized as yet, has been a topic of considerable research, particularly in wheat (Stermer 1972, Schatzki and Fine 1988, Schatzki and Keagy 1991, Keagy and Schatzki 1991, 1993, Haff and Slaughter 1999, Haff and Toyofuku 2000, Haff 2001, Karunakaran et al. 2003, Haff and Slaughter 2004).

Significant work has been done using X-rays to detect defects in apples. Schatzki et al. (1997) determined that X-ray images produced on a linescan X-ray machine revealed many internal defects, including senescence browning, watercore and stem rot. Also included were a limited number of X-ray images containing codling moth damage, but the number of samples was too small to make significant conclusions. Human recognition tests using these images scrolled across a computer screen showed that recognition rates of all defects became unacceptable as the scrolling speed approached rates found on a commercial packing line; therefore, a successful sorting system would require machine recognition. X-ray has also been shown to be an effective tool for the detection of bruising in apples (Diener et al. 1970, Ziegler and Morrow 1970) and for density and water content measurements (Tollner et al. 1992). Lammertyn et al. (2003) used X-ray CT imaging to detect core breakdown in pears, and some work has been done developing algorithms for the detection of watercore damage in X-ray images of apples (Kim and Schatzki 2000, Shahin et al. 1999), but no significant work has been reported for the detection of insect infestations.

The objective of this study was to examine current X-ray technologies for their potential use to detect insect infestations on a fruit packing line.

Materials and Methods

X-ray CT imaging. 'Fuji' and 'Delicious' apples and 'Bing' cherries were infested by hand with codling moth larvae from a colony reared at the USDA-ARS Yakima Agricultural Research Laboratory in Wapato, WA (Hansen et al. 2000a, 2000b). Developmental stages ranged from second to fifth instars. Pie cherries (cultivar unknown), infested with the western cherry fruit fly, *Rhagoletis indifferens* Curran (Diptera: Tephritidae), were collected from abandoned orchards near Cle Elum, WA. They were compared with uninfested 'Bing' cherries obtained from local vendors. Computed tomographic images (radiographs) of whole infested fruits were produced at Yakima Valley Memorial Hospital, Yakima, WA, using a Hi-Speed CT unit (GE Medical Systems, Waukesha, WI). Exposures were set at 120 kV and 160 mA. CT images were obtained using a helical technique with a slice thickness of 1 mm and reconstructed every 1 mm through each fruit specimen. Life size images were directly transferred to negative film. The fruits were dissected the next day to verify infestation.

Film imaging. Organically grown red 'Delicious' apples were obtained locally and infested with second instar codling moth. Whole apples were X-rayed daily on Kodak Industrex 100 film in a Faxitron film cabinet at settings of 50 KeV and 3 mA. Digital images of the X-rays were produced using a film scanner, and results were compared with those obtained using CT X-ray imaging.

Fig. 1. Photograph of cut fruit (top) and CT radiograph of whole fruit (bottom) of the same ‘Fuji’ apple infested overnight by fourth-instar codling moth: healthy tissue on top half of the fruit and feeding tunnels at the bottom.

Results and Discussion

The radiographs produced conspicuous images. In apple, healthy fruit tissue was characterized in the negatives by uniform light-colored areas gradually darkening toward the periphery (Fig. 1). The seed core, a vacant region within the center of the fruit, was solid black, as was all vacant areas. Seeds were indicated by small white elliptical shapes. The feeding tunnels produced overnight by larvae were obvious

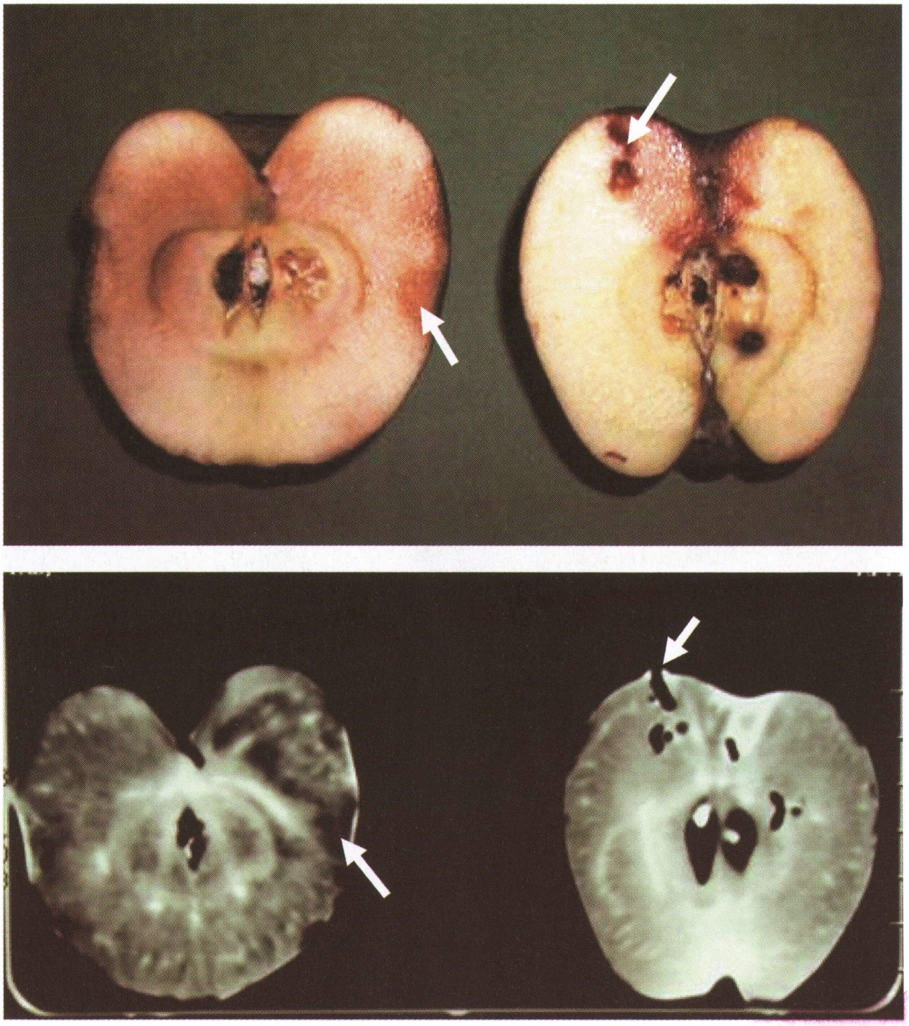

Fig. 2. Photograph of cut fruit (top) and CT radiograph of whole fruit (bottom) of the same 'Delicious' apples infested overnight by second-instar codling moth. Arrows at the top indicate feeding tunnels whereas those at the bottom show interior pulp damage.

(Figs. 1, 2), although individual larvae were not detected. Pulp damage due to disease was represented by highly contrasted areas, which were often streaked.

Similar observations were seen in radiographs of cherries. Undamaged pulp tissue was uniformly white with the central seed surrounded by a brighter ring than the much darker seed (Figs. 3, 4). The indented region connecting the stem was obvious. Feeding tunnels made overnight by second-instar codling moth were large dark areas penetrating the fruit pulp.

Radiographs of cherries infested with fruit fly larvae were diagnostic. Feeding damage caused by fruit fly larvae differed from that of codling moth larvae in that a gap separated the fruit pulp from its seed (Fig. 4). Presumably, this was due to feeding by the larvae or by the fruit retracting tissue in response to larval feeding.

Although the CT scans are too complex and expensive to be incorporated on a commercial packing line, they indicate that radiography is a potential method to detect insect infestations in real-time. A commercial system would likely use digital detectors, which yield images similar to scanned film X-rays. Results of the scanned film X-rays of apples infested with codling moth are shown in Fig. 5. Feeding tunnels are marginally detectable 4 days after introduction of the larvae, and are easily detectable after 8 days.

Whereas radiography appears to have the potential for on-line detection of infested fruit, the labor involved in removing the detected infestations from the process stream would still be an issue that needs to be addressed. The use of computer algorithms to automatically detect infested fruits in digital X-ray images would alleviate this problem. Production line would efficiently reduce labor costs yet maintain high accountability for eliminating flawed fruits.

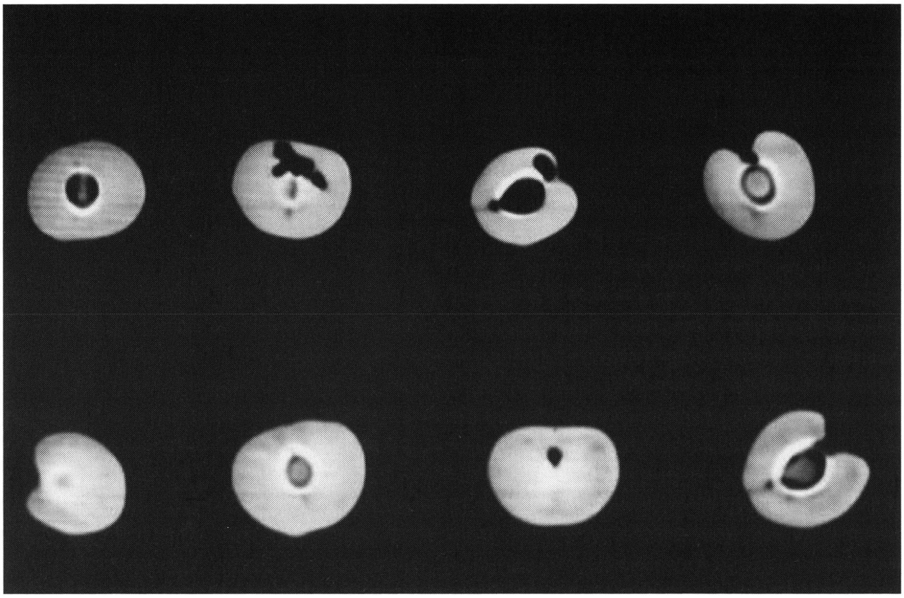

Fig. 3. CT images of whole ‘Bing’ cherries: Samples infested with codling moth larvae are shown in the top row whereas noninfested samples are shown on the bottom.

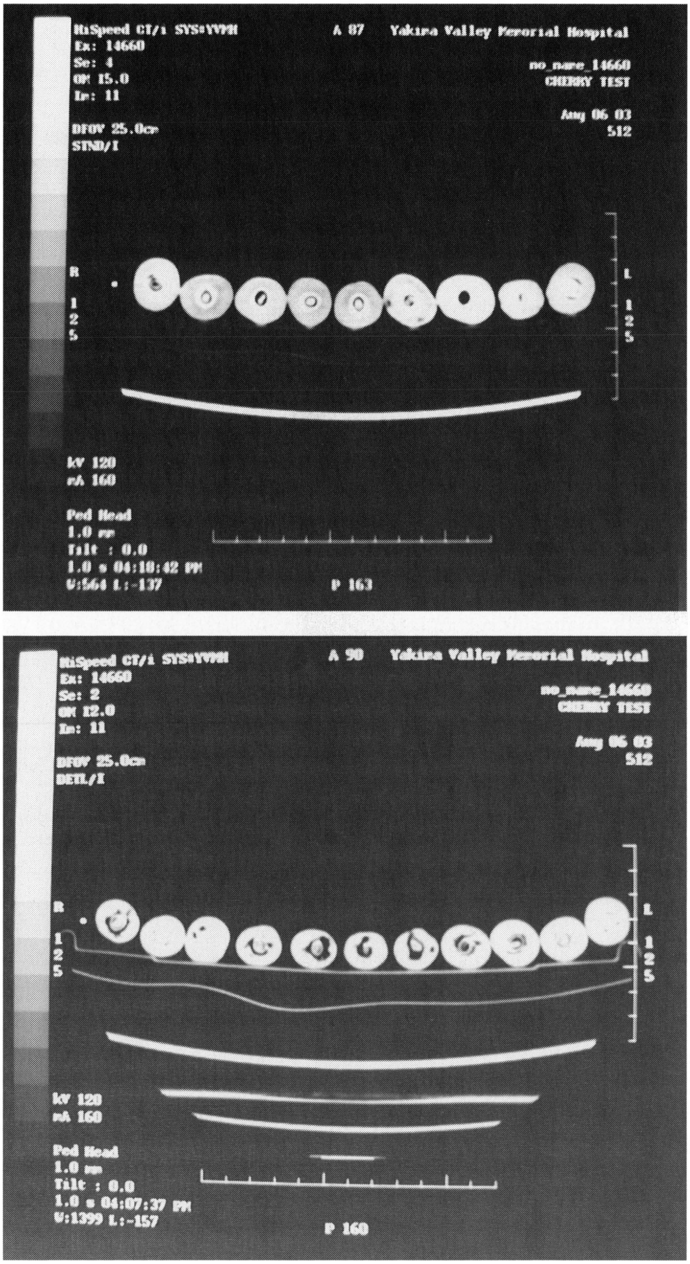

Fig. 4. CT radiographs of whole "pie" cherries from abandoned trees. Top sample is noninfested, whereas that on the bottom is infested with larvae of the western cherry fruit fly. In infested samples, the fruit pulp appears to separate from the seed.

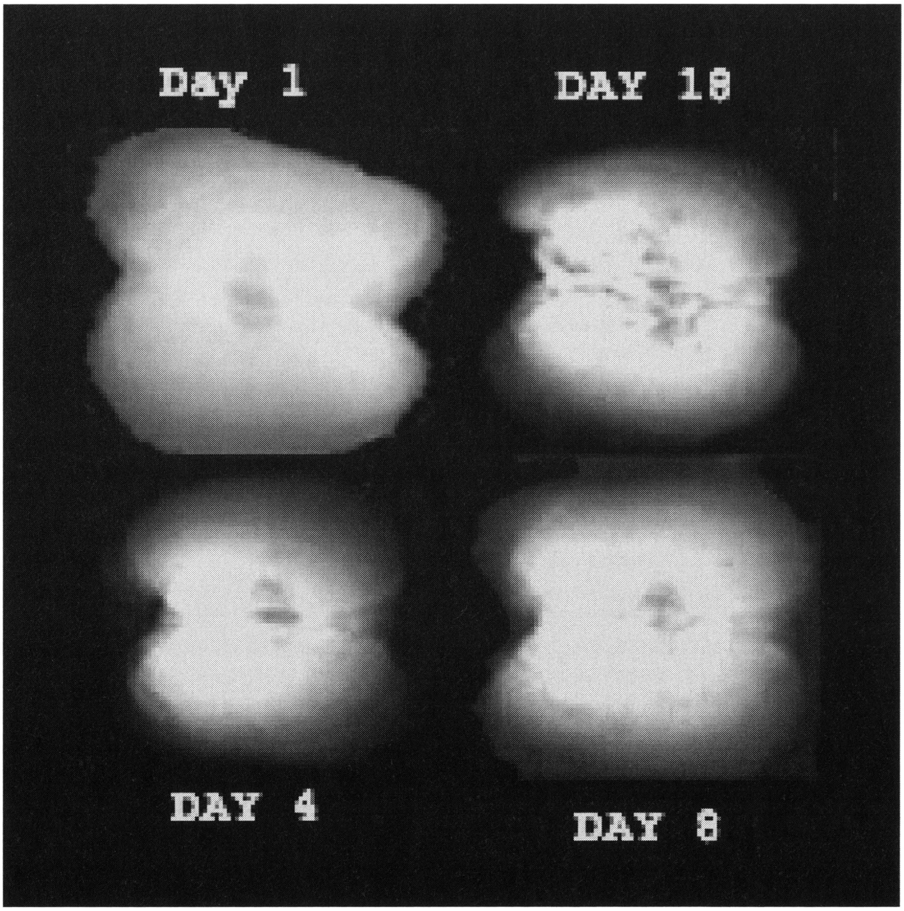

Fig. 5. Digitized film radiographs of whole apples infested with the codling moth larvae; days after infestation indicated.

Conclusion

Whereas not practical for on-line fruit inspection, CT X-ray imaging has demonstrated the potential use of X-ray imaging for the detection of insect infestations. Digitized film X-rays of infested apples suggest that more practical forms of X-ray imaging using digital detectors may be able to accomplish on-line detection at a reasonable cost. The development of automatic recognition computer algorithms would help reduce the cost further. The potential benefits to the fruit industry suggest that further research to develop a real-time X-ray inspection system with detection algorithms is justified. A test should be done as a next step to determine if the techniques work in identifying infested fruits in a blind trial.

Acknowledgments

The authors thank Memorial Hospital, Yakima, WA, for providing the radiographs; M. L. Heidt for laboratory assistance; and P. J. Landolt (ARS-Wapato), C. O. Calkins (ARS-Wapato), and C. S. Burks (ARS-Parlier) for reviewing this ms. This article reports the results of research only. Mention of a proprietary product does not constitute an endorsement or recommendation for its use by USDA.

References Cited

Anon. 2002. Apples in Washington state. Washington State University Cooperative Extension. Wenatchee, WA. http://www.ncw.wsu.edu/treefruit/aplcrop.htem.

Diener, R. G., J. P. Mitchell and M. L. Rhoten. 1970. Using an x-ray image scan to sort bruised apples. Agric. Eng. 51: 356-357, 361.

Haff, R. P. 2001. X-ray inspection of wheat for granary weevils. PhD Dissertation. U.Calif. Davis.180 pp.

Haff, R. P. and D. C. Slaughter. 1999. X-ray inspection of wheat for granary weevils. Am. Soc. Agric. Eng. Paper #99-3060. St. Joseph, MI.

Haff, R. P. and D. C. Slaughter. 2004. Real-time x-ray inspection of wheat for infestation by the granary weevil, *Sitophilus granarius* (L.). Trans. Am. Soc. Agric. Eng. 47: 531-537.

Haff, R. P. and N. Toyofuku. 2000. An economical method for x-ray inspection of wheat. Am. Soc. Agric. Eng. Paper #00-3069. St. Joseph MI.

Hansen, J. D., S. R. Drake, H. R. Moffitt, J. L. Robertson, D. J. Albano and M. L. Heidt. 2000a. A two-component quarantine treatment for postharvest control of codling moth on apple cultivars intended for export. HortTechnolog 10: 186-194.

Hansen, J. D., S. R. Drake, H. R. Moffitt, D. J. Albano and M. L. Heidt. 2000b. Methyl bromide fumigation of five cultivars of sweet cherries as a quarantine treatment against codling moth. Horttechnology 10: 194-198.

Karunakaran, C., D. S. Jayas and N. D. G. White. 2003. Soft x-ray inspection of wheat kernels infested by *Sitophylus oryzae*. Trans. Am. Soc. Agric. Eng. 46: 739-745.

Keagy, P. M. and T. F. Schatzki. 1991. Effect of image resolution on insect detection in wheat radiograms. Cereal Chem. 68: 339-343.

Keagy, P. M. and T. F. Schatzki. 1993. Machine recognition of weevil damage in wheat radiograms. Cereal Chem. 70: 696-700.

Kim, S. and T. F. Schatzki. 2000. Apple watercore sorting system using x-ray imagery: I. Algorithm development. Trans. Am. Soc. Agric. Eng. 43: 1695-1702.

Lammertyn, J., T. Dresselaers, P. Van Hecke, P. Jancsók, M. Wevers and B. M. Nicilaì. 2003. MRI and x-ray CT study of spatial distribution of core breakdown in 'Conference' pears. Magn. Reson. Imaging 21: 805-815.

Schatzki, T. F. and T. A. Fine. 1988. Analysis of radiograms of wheat kernels for quality control. Cereal Chem. 65: 233-239.

Schatzki, T. F. and P. M. Keagy. 1991. Effect of image size and contrast on the recognition of insects in radiograms. SPIE Proceedings 1379: 182-188.

Schatzki, T. F., R. P. Haff, R. Young, I. Can, L.-C. Lee and N. Toyofuku. 1997. Defect detection in apples by means of x-ray imaging. Trans. Am. Soc. Agric. Eng. 40: 1407-1415.

Shahin, M. A., E. W. Tollner, M. D. Evans and H. R. Arabnia. 1999. Watercore features for sorting red delicious apples: a statistical approach. Trans. Am. Soc. Agric. Eng. 42: 1889-1896.

Stermer, R. A. 1972. Automated x-ray inspection of grain for insect infestation. Trans. Am. Soc. Agric. Eng. 15: 1081-1085.

Tollner, E. W., Y.-C. Hung, B. L. Upchurch and S. E. Prussia. 1992. Relating x-ray absorption to density and water content in apples. Trans. Am. Soc. Agric. Eng. 35: 1921-1928.

Ziegler, G. B. and C. T. Morrow. 1970. Radiographic bruise detection. Am. Soc. Agric. Eng. Paper # 70-553. St. Joseph, MI.